

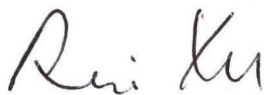
Printing Processes Used to Manufacture Solar Panels

An Honors Thesis (HONRS 499)

by

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Abstract

There is a growing need for renewable, clean energy sources, and solar power is a good option in numerous instances. Photovoltaic solar panels are now being manufactured using a number of various methods, and different printing processes are being incorporated into the manufacturing process in a number of cases. Screen printing seems to be the most prevalently used printing process to make solar cells, but there are also companies using offset web press type methods to put material onto foil, as well as creating solar cells with inkjet printing. The printing of solar cells has helped to reduce manufacturing costs in most cases and have also increased the various applications where solar power can be used. There are many more options for photovoltaic solar panels now, not just the traditional ones that are often placed on rooftops. This variety of solar panels is partially thanks to the implementation of printing processes during the production of the cells.

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Introduction

With ever-increasing political and economical oil conflicts as well as climate change, there is a growing need for renewable, clean energy sources. Wars have been caused in part to protect oil supplies, and millions of tons of pollutants and greenhouse gases are emitted into the atmosphere every year due to the burning of fossil fuels to create energy. There is no other area of technology that can both “meet the challenges of climate change and secure an energy supply in an intelligent manner” (Wengenmayr, 2008, p.1). A number of options for new technologies of renewable energy exist from geothermal to wind to hydrogen fuel cells to hydropower, but one of the most accessible to the general population and widely used technologies is solar energy. Solar power creates no noise when it is working, “is non-polluting, does not generate greenhouse gases, and creates no waste products,” (Brenner, 2010, p. 27), which is also why it is an increasingly preferred renewable energy. The potential for solar power is also immense. The energy from the sunlight that strikes the earth for just forty minutes is equal to the global energy consumption for an entire year (Zweibel, Mason, & Vasilis, 2008). All of that energy is not of any use, however, unless it can be captured and utilized. A good method to harness this immense amount of energy and use it as electricity is through the use of photovoltaic (PV) energy systems.

Photovoltaic Power

According to the U.S. Department of Energy (2008), “the diversity, adaptability, and modularity of PV technology make it distinct from other renewable resources.” Solar photovoltaic power is very useful in that it can be made in a number of ways from a variety of materials and used for numerous applications. Photovoltaic cells can be used for anything from a small strip that powers a simple calculator to personal panels on homes to larger commercial

settings and solar farms spread out over vast areas of land. Photovoltaic modules are also useful since they have minimal maintenance costs and are extremely long lasting, with some manufacturers offering up to 25-year warranties (Brenner, 2010). In the world in 2008, photovoltaic systems were actually the largest producer of electricity directly from solar energy, in terms of kWh produced per year (Vanek & Albright, 2008).

The photovoltaic or PV cell is a type of technology that uses semiconducting materials to convert the energy in sunlight to usable electricity. Derived from Greek, the term photovoltaic can be translated as “electrical energy from light” (Wengenmayr, 2008, p.42). The cells transfer the energy of the photons penetrating the solar panels to electrons that are “channeled into an external circuit for powering an electrical load” (Vanek & Albright, 2008, p. 249). A PV panel is made up of multiple photovoltaic cells, anywhere from 50 to 120, which are connected together in an electrical circuit that can then be connected to an exterior circuit at a single point. A whole PV system is often comprised of a number of panels so that there is a greater, more desirable amount of voltage produced (Vanek & Albright, 2008). These PV cells take on many forms and are produced in a number of different ways, often including various printing processes.

Printing Solar Cells

In order to make the use of solar power a likely alternative to fossil fuels, it needs to be economically comparable to conventional energy sources like coal, natural gas, and oil. This matter of cost is the largest issue facing the success of photovoltaic solar panel use. Efficiency of solar cells is the percentage that they are efficient at “converting the radiation from the sun into electricity for the area of the active part of the module” (Brenner, 2010, 29). Efficiency is possibly the most important factor when determining the overall use and quality of a solar cell

and plays a large role in overall cost reduction. The two main strategies to reduce the cost of power production in photovoltaic devices are to increase efficiency and lower production costs of the starting materials (Wengenmayr, 2008). Implementing different printing processes throughout certain steps of manufacturing has recently helped to accomplish both efficiency and lower costs. Certain printing processes like screen printing, inkjet printing, and even a web press offset type of printing all lend themselves to being just what is needed to make various types of solar cells. These processes are recently becoming a large part of solar cell manufacturing for different kinds of photovoltaic solar energy, each with their own benefits and drawbacks. It is important to understand the different types of solar cells and materials that are used to make them to see just where these printing processes can fit in.

Traditional PV material

Conventional solar cells are made from silicon, are flat plated and rigid, and these cells generally have the highest efficiencies. Crystalline silicon (c-Si) is the most widely used and most efficient material to use in the production of photovoltaic solar cells, with commercial efficiencies sometimes reaching 20%. It is estimated that about 80% of all photovoltaic solar panels produced are created with crystalline silicon, and this material is especially useful since it has shown long-term performance and reliability (Crystalline, 2010). Crystalline silicon cells are made from silicon wafers that could be either mono-crystalline or multi-crystalline structures, depending on what is available or what is needed for that particular process. All structures of pure silicon will be facing shortages of resources, though, especially since the material is used in other semiconductor industries as well as solar PV. Silicon is an element that is plentiful in the earth's crust, but most of it occurs in compounds that would be costly to extract the pure silicon

from them (Vanek & Albright, 2008). Crystalline silicon has been the go-to material to make efficient solar panels, but with shortages, as well as the general high costs of silicon, other options have been developed with other materials or simply smaller amounts of silicon.

Thin Film PV Materials

Thin film solar cells offer the most variety of material options for the production of solar cells. The cost savings also seem to be very large, and the versatility of applications with thin film could vastly increase the use of solar power. While there are numerous different materials that have been used for thin film, the most widely used at present are amorphous silicon, organic polymers, and a combination of conductive metals including compounds of copper, indium, diselenide, and sometimes gallium.

In terms of the more conventional materials, amorphous silicon (a-Si) can be mass produced more easily than crystalline silicon, and can be very thin, even to the point of being flexible, so much less amounts are needed (Vanek & Albright, 2008). Since the atoms are not arranged in any particular order, like in crystalline structure, there is more flexibility with what can be made with amorphous silicon. The material is full of defects naturally so impurities are not a problem and it can be applied over very large surfaces, making it more usable than crystalline silicon even though it does not have the same quality of electrical properties (Amorphous, 2009).

There are a number combinations of conductive and semi-conductive metals and compounds that can be used to create solar cells, but the most acclaimed and most common seems to be one consisting of copper-indium-diselenide, also known as CIS (Goetzberger, Knobloch, & Voss, 1998). As early as 1978, high efficiencies without degradation were

observed, which made this a very important material in the thin film solar industry. Recently, a similar but even more productive combination of copper, indium, selenium, and gallium, also known as CIGS, has been used (Inslee & Hendricks, 2008). These materials help to make the mass production of solar cells more of a reality, and since CIGS can potentially have similar efficiencies to traditional cells, about 19.5% (Contreras et al., 2005), this is one of the most promising PV technologies.

A company called Konarka Technologies has developed thin film solar PV cells from organic polymers in the form of their "Power Plastic." These organic photovoltaics are a third generation type of solar power that uses a photo-reactive polymer that can be combined with several other very thin layers to be used in a number of products. The Power Plastic can be printed on large rolls of flexible substrates, is made from recyclable materials, and converts light to energy both outdoors from the sun and indoors from a light bulb (Our Technology, 2010). Another application of organic polymers is to be used as a dye that is a combination of nanoparticles that convert light to electricity (Fraunhofer-Gesellschaft, 2008). Both of these applications of organic polymers immensely help reduce the cost of manufacturing solar cells but are not as efficient as silicon-based cells, and the longevity is not known of these new cells.

Screen Printing

The basic principle of the process of screen printing is simply the use of a stencil to reproduce the same image over and over again. This is currently conventionally done with the use of a mesh screen coated with light-sensitive emulsion that is then exposed to light with the desired positive image blocked, and then washed out to create the mesh stencil. There are other ways to make the stencil, but that use of photographic emulsion is most common. Ink is then

applied to the screen and pushed through with a squeegee to transfer the ink on the open image area to the desired substrate. This process can be repeated as many times as the screen materials will last. Screen printing is one of the most versatile printing processes because almost anything from glass to paper to fabric to plastic can be printed on, and a very thick amount of ink can be laid down, unlike in other printing processes. There are numerous factors that need to be taken into consideration when screen printing depending on the type of materials and images that are being printed. Factors including mesh count, screen angle, emulsion-on-mesh thickness, stencil surface smoothness, ink type, how detailed the image is, how many impressions the screen can last, and squeegee pressure can all impact the overall quality of the product that is being printed. This screen printing process has been used as part of the process to make conventional silicon solar cells due to its versatile nature.

According to Peter Brenner (2010, p. 26), global marketing manager of photovoltaics for DuPont Microcircuit Materials, "Screen printing photovoltaic cells is the most reliable method and fastest growing application in industrial printing." Screen printing is the most commonly and conventionally used printing process throughout the manufacture of photovoltaic solar cells. In fact, over 90% of all crystalline silicon modules are manufactured using screen printing, and about 60% of flexible thin film modules use screen printing in the manufacturing process (Brenner, 2010, p. 29).

The way that screen printing is used in the process of making solar cells is that PV solar cells are often metalized through a screen printing process. This is the application of three different types of metallization pastes onto the c-Si cell. The first paste is the front-side silver used on the side facing the sun that makes up the collector gridlines and the silver bus bars, the second is the rear-side tabbing silver or silver-aluminum, and the third is the rear-side aluminum

paste that actually reacts with the silicon to create the back surface field (Brenner, 2010). The screen printing process is especially useful in applying these pastes since consistency in each application as well as the ability to lay down different thicknesses for the different types of pastes are both very important. However, just like screen printing anything, a number of variables involved in screen printing photovoltaics need to be monitored: ink composition (solid content, viscosity, rheology, evaporation rate, dispersion), press setup (squeegee durometer and shape, attack angle, squeegee pressure, print speed, snap off, registration control), screen/stencil (mesh count, wire diameter, percent of open area, emulsion thickness, mesh tension), and the environment (room temperature, humidity, air turbulence, cleanliness, substrate surface, shelf life of ink and screens) (Brenner, 2010, p. 28). Each of these variables is generally something that needs to be considered in any type of screen printing, but it is especially important with printing PV modules due to the nature of the materials and needed accuracy.

Another way that screen printing is utilized in the manufacture of solar panels is through the use of organic dye that is a combination of nanoparticles, which serves as a semiconductor to convert sunlight to energy. The versatility of this dye allows for different colors and designs to be printed, making this an excellent option to be integrated into the façade of a building or to serve as a decorative element. These panels could be integrated into windows and not only convert sunlight to electricity but also serve as a sunshade to the interior of the building, saving additional energy. Even though screen printing this dye onto glass makes it an excellent choice for building integration, the cells only have an efficiency of about 4%, so they are not yet going to be competitive with conventional silicon panels. The longevity of this technology is yet to be determined as well, though it did seem to perform well in initial tests (Fraunhofer-Gesellschaft, 2008). Even with these drawbacks, this organic dye could be a very popular choice by consumers

due to its more aesthetically pleasing qualities and options to have whatever design or color is desired.

Screen printing has been the prime choice for the metallization of conventional solar cells. It is the type of process that can print on anything with any type of paste substance at just about any thickness, making it very versatile and useful in the traditional PV manufacturing process. With high costs of materials, many other options for solar cells have been developed, and screen printing has also helped play a role with those. The ability to print an organic dye that serves as a semiconductor solar panel and could be made into potentially any number of colors and patterns could help make solar panels more accessible and desirable to consumers. The use of screen printing in this process is very important, and screen printing's adaptable qualities have lent themselves to be extremely useful in the production and improvement of manufacturing solar cells.

Inkjet Printing

Inkjet printing is one of the newest and most experimental methods used to make solar cells, and it could potentially have a very big role in making solar panels accessible to everyone. The most common type of personal computer printers use inkjet technology and it is also used widely in industrial applications such as the production of numerous microscopic items, the formation of conductive traces for circuits, and the manufacture of color filters in LCD and plasma displays (Clark 2008). Inkjet printing is a non-impact printing that uses a number of nozzles to spray ink droplets directly onto the paper or substrate without touching it (Tyson, 2001). This basic principle makes inkjet printing very useful in that not only can it spray onto a number of different surfaces, but a number of materials, not just conventional printing ink, can

be sprayed. Inkjet printing has been recently used in the production of both flexible thin film solar cells as well as more conventional rigid silicon cells.

Using inkjet printing to apply semi-conductive material onto flexible substrates that could result in the formation of a thin film PV solar cell has the potential to become available to anyone with an inkjet printer. While this is not the case yet, many places are using inkjet printing to reduce manufacturing costs and trying to increase efficiencies of thin film solar cells. Konarka Technologies is using inkjet printing as part of the production process of their Power Plastic thin film solar cells, which are made of organic polymers. This material has been in production and development for a few years, and in 2008, inkjet printing was used, making the process much cheaper than it previously had been (Masamitsu). This paper-thin plastic has infinite possibilities and can be applied to any flexible surface such as tents, umbrellas, and handbags, but there are a few drawbacks. The efficiency of this inkjet printed material is only 3-5%, so to get anywhere near the amount of energy a conventional silicon solar cell can get, there would need to be a very large area available to lay down this Power Plastic. These cells also only last about a couple of years, as opposed to decades that conventional cells last (Bullis, 2008). These drawbacks currently limit the use of the product, but the benefits are still very great since potentially anyone could print these cells. That may be a few years away, but the versatility and massive amount of places this plastic could be used are still nothing to be taken lightly. Inkjet printing plays a role to help make this happen.

Inkjet printing is also now being used in place of screen printing to make electrical connections during the process of making more conventional crystalline silicon solar modules. The inkjet method can be more precise, and since the print heads do not make contact with the silicon, a thinner, more fragile piece can be used. Conventional screen printing methods need to

use silicon wafers that are at least 200 micrometers thick because any thinner wafer will likely break. It is estimated that 100 micrometers of silicon can be used with this inkjet process, and since silicon can account for 75% of the total cost of materials and production, this could greatly reduce overall costs (Bullis, 2009). The silver gridlines can be printed with inkjet printing and the ink used is more conductive than the silver paste in screen printing. Maikel van Hest, a scientist at the National Renewable Energy Laboratory, notes more precise lines of 35 to 40 micrometers wide, compared with 100 to 125 micrometers wide with screen printing can also be printed (as cited in Bullis, 2009). This ultimately means that not as much silver needs to be used, saving additional money and resources. The thinner lines can also block less of the solar collecting material so that the sun's radiation can hit more of the surfaces that are actually collecting it, as opposed to bouncing off because of the thicker silver lines. These thinner lines make the cells more efficient, though the amount of increased efficiency is unknown.

No matter what application inkjet printing is being used in, the process is proving to be a very important part of making photovoltaic solar cells more economical and more accessible. While currently it is only used in mass production, the potential of being able to print on a personal printer is definitely a considerable advantage that this process has over any of the others. Not only is inkjet printing improving already developed PV manufacturing processes, but it is also a key component to an entirely new type of thin film that could be used for any number of purposes. Inkjet printing is helping to reduce costs of manufacturing and increase the efficiency and availability of solar cells, which are currently vital goals of the photovoltaic solar industry.

Web Printing

Though not exactly using the principle of offset lithographic printing, there are companies using web press applications to coat semiconducting materials onto flexible substrates. The substrates that are currently being used are plastics and metal foils. Offset printing is a type of planography, because the plates used during printing are completely flat. The principle of offset lithography is that the oil-based ink only sticks to the hydrophobic image area on the plate, is transferred to a blanket, and then transferred onto the substrate. Web offset printing is a continuous process that prints on rolls of substrates, though it is still an indirect process due to the nature of offset lithographic printing. Newspapers, for instance, are often printed by an offset web press and then cut down into the necessary sheets. With the manufacture of solar cells, certain principles of web offset printing are applied, and they are shown to greatly decrease costs and increase production capabilities.

Nanosolar is a company that prints the semi-conductive compound of copper, indium, gallium, and selenium (CIGS) onto thin foil. The company uses a web press application and “can produce a hundred feet of continuously rolled solar cell per minute” (Inslee & Hendricks, 2008, p. 72). Their nanoparticle ink mixture, consisting of CIGS and the necessary components for proper dispersion, is coated onto “a specially-prepared proprietary alloy of metal foil using high throughput coating/printing techniques” (Technology, 2009). This method of printing has replaced the conventional process of high-vacuum deposition, which is much more time consuming. Nanosolar has taken the economics and processes of printing and applied them to the formation of solar cells and seems to have done so very successfully. Their process should make this type of solar cell electricity as cheap as the current electricity taken off the grid (Inslee & Hendricks, 2008). The National Renewable Energies Laboratory certifies that their solar cells

have up to a 15.3% efficiency (Nanosolar Communications, 2009), which is comparable to conventional crystalline silicon cells. The product itself is also thin and flexible, which could be useful in a number of applications. Nanosolar's thin film cells are much more economical than traditional silicon cells, and can be mass produced very quickly thanks to the use of a printing process.

Konarka's Power Plastic uses not only inkjet printing but also a web press application in some instances. They use a type of coating process that is continuously rolled to get the right substrate combination of usable photographic film and organic polymers (Bullis, 2008). Though not exactly a printing process, this application is most definitely inspired by traditional web printing, and this is an important part of the process of the manufacture of Power Plastic.

Web press applications are fairly new to the photovoltaic solar cell industry, but are really playing a very important roll in the ability of mass production. This ultimately makes the cells more economical, and in the case of Nanosolar, the cells are fairly comparable in efficiency. The use of web printing is definitely a help for the solar cell industry.

Conclusions

In these times of uncertain energy sources and the impacts that they are having on the atmosphere, clean, renewable solar energy is a good alternative. However, it is still more expensive than what consumers are currently using, and in order to be a viable option, it has to be attainable and affordable. With the use of different materials and thin film technologies, the use of photovoltaic solar energy for the average person is becoming more of a reality.

Printing processes have helped the photovoltaic solar industry by providing useful solutions to decrease manufacturing costs and increase the availability of these technologies to

consumers. Screen printing has been used for years as a good option for metallization when producing traditional crystalline silicon solar cells and has more recently been used as the application for organic semi-conducting dye used to make photovoltaic solar cells. Inkjet printing is useful in the production of solar cells as both a new replacement for the screen printing metallization and in the manufacturing of thin film solar cells. Even web offset printing has inspired some of the processes used to make thin film solar cells, and it is a very effective way to mass produce these cells quickly. Each of these processes has helped to make solar cells more affordable and attainable.

Thin film solar cells would not be as widely produced and researched if it were not for the printing processes that helped make them as useful as they currently have become. Conventional crystalline silicon solar cells are efficient and have great longevity, but they can not be used everywhere since they are rigid, and they are also very expensive and resource intensive to produce. Thin film seems to be the direction that solar cells are heading, and if they can get equal efficiencies then there is no reason why they should not be used as replacements for conventional energy methods. Thin film cells can be used on roofs as well, but they can also be placed just about anywhere and are more aesthetically pleasing, which would make them more marketable than conventional solar panels. There are a number of new developments in the photovoltaic solar industry, and with the help of processes inspired by the printing industry, it will continue to develop and eventually PV cells will be a highly sought-after energy source.

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